Journal of Human Kinetics volume 82/2022, 233-241 DOI: 10.2478/hukin-2022-0080 233
Section IV – Behavioural Sciences in Sport & Sport for the Disabled

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Handcycling Training in Men with Spinal Cord Injury Increases Tolerance to High Intensity Exercise

by
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Individuals with spinal cord injury are characterised by reduced physical capacity as compared to able-bodied persons, and are at risk of developing cardiovascular disease. The study aimed to evaluate the differences in physiological responses to an exercise test in handcycling-trained vs. able-bodied-trained and non-trained men. Eight males with spinal cord injury who were trained in handcycling, eighteen able-bodied males who were trained in powerlifting, and fourteen physically active non-athletes performed a graded arm crank ergometer test. The following physiological indices were measured before and during the test: heart rate, oxygen uptake, and blood lactate concentrations. Aerobic capacity was significantly higher in athletes with spinal cord injury compared to able-bodied athletes ($p<0.01$) and the control group ($p<0.01$). The heart rate achieved by handcycling-trained athletes was significantly lower as compared to powerlifters ($p<0.01$), however, the oxygen pulse was significantly higher ($p<0.05$). Handcycling-trained athletes reached significantly higher peak power (P_{max}) during the graded arm exercise in comparison with powerlifters, and significantly higher post exercise blood lactate concentration ($p<0.05$). The lactate threshold was observed at a significantly higher P in individuals with spinal cord injury compared to able-bodied-trained ($p<0.05$) and non-trained men ($p<0.001$). Athletes with spinal cord injury were found to have excellent aerobic capacity and better physiological adaptation to the maximal graded exercise test as compared to able-bodied-trained men. These findings emphasize the importance of regular physical exercise and its potential therapeutic role in the prevention of cardiovascular disease in patients with spinal cord injury.

Key words: *aerobic capacity, disabilities, physique enhancement, paraplegic endurance athletes.*

Introduction

Physical exercise training at both recreational and professional levels has been shown to improve physical and mental wellbeing of people with different types of disability who are often pitied and seen limited in their ability to be independent and successful (Gawlik et al., 2017; Martin, 2013; Zwierzchowska et al., 2015). An improvement in physical, emotional and social functioning, enhanced perception of competence, and increased physical performance especially among athletes are amidst the benefits of exercise training (Kosma et al., 2007; Taube and Greer, 2000). Moreover, all of these changes lead to the increased quality of life for those with disabilities (Stevens et al., 2008).

Spinal cord injury (SCI) is one of the most severe forms of physical disability (Jović, 2011). Depending on the severity and the location of the injury, SCI leads to a partial or complete loss of sensory and/or motor function below the level of the lesion (Alizadeh et al., 2019). Injury of the thoracic, lumbar or sacral spine can cause paraplegia and impairment of sensory and/or

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Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 82/2022 in April 2022.

motor function of the legs and potentially the abdomen, whilst injury of the cervical spine is usually associated with tetraplegia and additional impairment of sensory and/or motor function of the arms (Chin et al., 2017). SCI does not only result in motor and sensory impairment, but also disruption of the autonomic system and unique changes in cardiorespiratory, neuromuscular, thermoregulatory and metabolic function (Hou and Rabchevsky, 2014; Krassioukov, 2012). Particularly individuals with SCI at the cervical or high-thoracic level will experience lifelong abnormalities in systemic arterial blood pressure control (Krassioukov and Claydon, 2006). In general, their resting blood pressure will be lower as compared to that of able-bodied individuals, but they can also experience episodes of life-threatening hypertension (autonomic dysreflexia) which often results from disturbances in the heart rate and rhythm (Hou and Rabchevsky, 2014). Moreover, impaired sympathetic cardiovascular innervation, which, in the presence of insufficient skeletal muscle pump for venous return resulting from motor deficit and loss of skeletal muscles, may lead to pooling of blood in the lower extremities and reduced blood flow in the upper body (Furlan and Fehlings, 2008). All of these changes negatively influence physiological responses to exercise as compared to able-bodied individuals and those with other types of disability (Bhambhani, 2002). Nevertheless, physical exercise therapy is a cornerstone of rehabilitation of patients with SCI (Kloosterman et al., 2009).

Exercise training needs to be adapted to the type and extent of disability as well as to the level of physical capacity of the person. Evaluation of physical capacity via an exercise test enables an objective assessment of the degree of motor and perceptual function impairment, acceptable exercise training volume (the product of exercise intensity, time and frequency as per Pescatello et al. (2014)), effectiveness of a medical treatment and rehabilitation as well as effectiveness of exercise training. Therefore, the objective of the study was to evaluate physical capacity of handcycling-trained men during a graded arm ergometric test. The study further aimed to describe the differences in physiological responses to the exercise test between handcycling-trained men, a contrasting group of upper-body trained athletes without a disability and non-trained men.

Methods

Participants

The group of handcyclists (HCycl) consisted of eight males with SCI who had been training handcycling for approximately five years. They had acquired SCI approximately 10 years before the study, which resulted in paraplegia caused by an incomplete injury of low cervical nerves C5 (n=1), C6 (n=1), C6-C7 (n=1), thoracic nerves Th6-7 (n=1), Th6 (n=1), Th12 (n=1), and lumbar nerves L1-L2 (n=1). They had been training handcycling at a frequency and duration of approximately 6 times/week for 2.3±0.3 hours/day. In addition to handcycling, resistance exercise had been a part of their training programme.

The group of powerlifters (PLift) consisted of eighteen athletes. They had been training for approximately 5 years at a duration of 1.5-2.0 hours 5 times/week according to different resistance training regimens. Mean training intensity was approximately 60, 80 and 100% of the maximal voluntary contraction (MVC) during the transition, preparatory and competitive phases of the training season, respectively. The training programme had mainly included exercises of the upper limbs.

Additionally, fourteen males who were physically active, but non-athletes, served as a control group (CG).

All studied males were non-smokers and did not take any prescribed medications or supplements increasing physical performance.

Design and procedures

Participants' aerobic capacity was assessed during a graded exercise test on an arm ergometer modified for synchronous arm movement (Monark 829, Sweden). The exercise test (ExT) started with a 3-min warm-up without resistance. Resistance was then added and increased every 3 min by 20W until volitional exhaustion (P_{max}). Participants were instructed during the test to maintain a minimum frequency of 60 revolutions per minute (rpm). The following physiological indices were measured continuously before and during the ExT: heart rate (HR), oxygen uptake (VO_2), carbon dioxide output (VCO_2), and minute ventilation (VE)

(MetaMax 3B Cortex analyser, Poland). VO_2 was utilised to estimate the metabolic equivalent of task (MET). MET was used as an indicator of the energy expenditure during the ExT as well as its intensity. Blood lactate concentrations (LA) were determined using the Biosen C_line method (EKF Diagnostic GmbH, Germany).

From seven days prior to and during the exercise test protocol, participants abstained from alcohol, coffee and tea consumption and did not perform any strenuous physical exercise. From three days prior to testing, all participants consumed a balanced diet with the energy value of 37 kcal/kg/day and 50-60% of the energy derived from carbohydrates, 15-20% from protein and 20-30% from fat. The nutritional value of the participants' daily diet and macronutrients intake were calculated using Dietus software (Warsaw, 1995) and compared to the tables of food(s) nutritional value (Kunachowicz et al., 2003). Participants' nutritional status was evaluated by measuring their anthropometric indices. The body mass index (BMI) was evaluated in all groups, whilst body fat (BF) content and fat free mass (FFM) were assessed only in the PLift group and the CG with a stand-on hand-to-foot 8-electrode body composition analyser which used the bioimpedance technique (Tanita, BIA, Japan).

Measurements of body composition of the PLift group included body mass (to the nearest 0.1 kg) using a chair medical scale WE150P3 K (MENSOR, Warsaw, Poland), body height to the nearest 0.5 cm while lying supine with straight legs and flexed feet using a non-stretch fiberglass fabric tape, the waist circumference (WC) and the hip circumference (HC) measured at the narrowest part of the waist after a normal expiration and around the widest portion of the buttocks, respectively. The body adiposity index, a novel index to estimate body adiposity, was measured in the HCycl group as a ratio of the hip circumference and body height (Gallagher et al., 2000).

The study protocol and potential risks associated with the participation were clearly explained to participants prior to obtaining informed written consent. Participants were informed about their right to withdraw from the study at any time. During the screening process, those reporting any health problems and with deviations from normal values for blood pressure were excluded.

The study was approved by the Ethics Committee at the Jerzy Kukuczka Academy of Physical Education in Katowice and conformed to the standards set by the Declaration of Helsinki.

Statistical analysis

All data are presented as the mean and standard deviation (SD). Due to the small size of the analyzed groups, the following statistical tests were used to determine any statistically significant differences between the groups: the Kruskall-Wallis test, the Spearman's rank correlation test and the nonparametric Bonferroni test. Microsoft Excel (Microsoft Corp., Washington, USA) and the Statistics Package v.12 (StatSoft Poland, 12.0) were used for data processing and analyses. The differences were considered statistically significant at $p<0.05$.

Results

Participants' characteristics

HCycl and control subjects had a normal BMI (BMI: 18.5–24.9m/kg²) (WHO, 2000), whilst the BMI of the PLift group was slightly above the normal range. The percentage of body fat estimated using the body adiposity index indicated that HCycl males were moderately overweight (BAI>20.8%). In the PLift group and the CG, body fat content (BF) revealed values within the normal range (Table 1).

Physiological response to the ExT

The HR measured in the last minute of the ExT (HR_{max}) was significantly lower in the HCycl group compared to the PLift group ($p<0.01$) and the CG ($p<0.01$) (Table 2). The analysis of variance showed a significant effect of HCycl (F=11.8; $p<0.01$) on aerobic capacity, which was greater in the HCycl group than in the PLift group and the CG. Relative (ml/kg/min) peak oxygen uptake (VO_{2max}), the criterion measure for aerobic capacity, was significantly higher in the HCycl group compared to the PLift group ($p<0.01$) and the CG ($p<0.01$) and showed *excellent* aerobic capacity of participants with SCI (Astrand and Rodahl, 1986). The PLift group and the CG reached similar VO_{2max} indicating *poor* aerobic capacity ($VO_{2max}<37$ml/kg/min) for this age group (20-29 years) (Astrand and Rodahl, 1986). A significantly higher maximal oxygen pulse (VO_{2max}/HR_{max}) was found in the HCycl group in comparison with the PLift group ($p<0.05$) and the

CG ($p<0.05$).

The HCycl group registered a significantly higher maximal blood lactate (LA_{max}) concentration in comparison with the PLift group ($p<0.05$). No significant differences were found between LA_{max} in the HCycl group and the CG. The lactate threshold (LAT) was observed at a significantly higher P (W) in the HCycl group compared to the PLift group ($p<0.05$) and the CG ($p<0.001$). HCycl athletes achieved a significantly higher maximal P during the ExT with comparison to the PLift group (180.0±58.9 vs. 153.0±19.5W, $p<0.01$) and the CG (180.0±58.9 vs. 110.0±18.8W, $p<0.001$).

Maximal VE (VE_{max}) of the HCycl group was significantly higher as compared to VE_{max} of the PLift group ($p<0.05$) and the CG ($p<0.01$). The metabolic equivalent of task (MET) was significantly higher in the HCycl group compared to the PLift group ($p<0.01$) and the CG ($p<0.05$). MET >6.0, observed in all three studied groups, also confirmed a high intensity of the exercise test (Haskell et al., 2007).

Table 1

Characteristics of the studied groups

Variable	HCycl n=8	PLift n=18	CG n=14
Age [years]	36.6±9.4	22.4±1.5	23.6±2.4
BM [kg]	63.2±7.6	76.5±5.4	72.1±5.6
BH [cm]	175.8±8.0	173.2±4.3	177.4±6.0
BMI [kg/m^2]	20.4±1.2	25.3±1.6	22.7±1.0
BF [%]	21.0±1.0 [x]	12.6±2.7	14.5±3.4
Training experience [years]	8.5±3.5	5.4±1.7	0

BM–body mass; BH–body height; BMI–body mass index; BF–body fat;
[x] estimated using the Body Adiposity Index (BAI); HCycl–handcycling-trained group;
PLift–powerlifting-trained group; CG–control group.

Table 2

Physiological variables in the HCycl and PLift groups and the CG in response to the exercise test.

Variable	HCycl n=8	PLift n=18	CG n=14
HR_{max} [1/min]	159±32**##	184±8	186±9
VE_{max} [l/min]	110.0±40.0*##	88.4±20.5	75.4±16.2
VO_{2max} [l/min]	2.7±0.8	2.5±0.4	2.3±0.3
VO_{2max} [ml/kg/min]	44.3±14.6**##	32.0±6.2	33.0±5.5
VO_{2max}/HR max [ml/1]	17.1±3.0*#	13.6±2.0	12.3±3.0
LAT [Watt]	130.0±40.0*###	110.0±12.8	80.0±22.8
MET	12.6±4.2**#	9.1±1.8	9.4±1.6
P_{max} [Watt]	180.0±58.9**###	153.0±19.5	110.0±18.8
LA_{max} [mmol/l]	9.9±3.7*	9.2±1.7	9.8±1.2

HR–heart rate; VE–minute ventilation; VO_2–oxygen uptake;
VO_2/HR–ratio of oxygen uptake to heart rate (oxygen pulse); LAT–lactate threshold;
MET–metabolic equivalent of task; P–power; LA-lactate concentration in blood;
max–measured in the last minute of exercise test;
**p<0.05; **p<0.01 HCycl vs. PLift; #p<0.5*
##p<0.01 ###p<0.001 HCycl vs. CG.

Discussion

SCI is a devastating injury leading to the loss of somatic and autonomic nervous system function. The higher the lesion and the greater its degree of completeness, the lower the physical capacity of the individual. Consequently, the capability to perform voluntary exercise at sufficiently high metabolic rates to stimulate the cardiopulmonary system for maintenance of health and aerobic/anaerobic fitness is reduced (Janssen et al., 2002). The present study aimed to assess physiological responses to a maximal exercise test in male athletes with incomplete SCI at low cervical, thoracic and lumbar levels and compare them to those of able-bodied powerlifters and physically active, but not trained men.

The major finding of the study was the excellent aerobic capacity of athletes with SCI whose VO_{2max} was significantly higher than that observed in able-bodied athletes and non-athletes. A study by Vinet et al. (1997) also demonstrated high values of VO_{2max} of athletes with paraplegia (spinal lesion level, T4-L3) who performed a graded wheelchair exercise on an adapted treadmill, however, it was lower than that observed in the present study (40.6±2.5 vs. 44.3±14.6ml/kg/min, respectively). It has been previously suggested that arm crank ergometry is less strenuous than wheelchair ergometry, and therefore, may result in higher values of VO_{2max} (van der Woude et al., 2001). Nevertheless, the literature is inconsistent, with some studies showing no difference in VO_{2max} achieved in arm vs. wheelchair ergometry (Tørhaug et al., 2006). In the present study, VO_{2max} of athletes with SCI was found to be significantly higher compared to VO_{2max} found in the able-bodied trained and non-trained groups. Contrary to the present findings, Baumgart et al. (2018) demonstrated that upper-body trained men (an ice sledge hockey player, two hand-cyclists, a wheelchair curler, a wheelchair judoist) with paraplegia reached 24% lower VO_{2max} compared to able-bodied also upper-body trained men (cross country skiers with half of training spent in modes including the upper-body), which confirmed lower physical capacity of those with SCI (Janssen et al., 2002). On the other hand, Schneider et al. (1999) observed similar VO_{2max} reached during arm crank ergometry by males with paraplegia and able-bodied males. The studied groups were physically active, but did not train any sport, and their VO_{2max} indicated *poor* aerobic capacity. It is worth noting that in the present study VO_{2max} of both the PLift group and the CG were comparable, and as low as shown by Schneider et al. (1999) confirming that resistance training mainly improves anaerobic and not aerobic performance. This observation could also be explained by the fact that the PLift group had not been engaged in exercise training for as long as participants from the HCycl group (5.4±1.7 vs. 8.5±3.5 years, respectively).

It is necessary to highlight that aerobic capacity is an indirect measure of the cardiovascular disease risk (Kohl, 2001), the main cause of mortality in chronic SCI, hence the present study observation of *excellent* aerobic fitness of the HCycl group is of significant importance and emphasizes therapeutic effects of regular physical exercise. The studied SCI group had been training handcycling nearly every day for at least 1 hour, yet still, they showed elevated levels of body fat as indicated by the BAI (%BAI > 21.0). This observation could be a consequence of an excessive energy intake, however, this would need to be confirmed by a dietary analysis, which is beyond the scope of this study. Additionally, SCI-induced paresis or paralysis below the level of lesion as well as the post-injury lifestyle can lead to accumulation of visceral fat and increased absolute body fat mass (Maruyama et al., 2008; Zwierzchowska et al., 2014).

SCI in both the acute and the chronic phase is associated with significant cardiac dysfunction resulting from the impairment of the autonomic system, particularly its sympathetic pathways (Furlan and Fehlings, 2008). This can be manifested as reduced chronotropic and inotropic effect on the heart during physical exercise, hence its diminished ability or inability to raise its rate adequately to increased physical activity (Schmid et al., 1998). In the present study, the HR_{max} of the HCycl group measured in the last minute of the graded arm cranking exercise test was significantly lower as compared to the HR_{max} observed in the able-bodied, trained (PLift) and non-trained (CG) groups. Schmid et al. (1998) demonstrated significant differences in the HR_{max} between individuals with different levels of SCI during a graded maximal exercise on a wheelchair ergometer. Those with paraplegia and the lesion below Th5 reached a significantly higher HR_{max} than did those with paraplegia and a higher-level injury (Th1-Th4). Interestingly, the HR_{max} of individuals with the T1-T4 lesion was comparable to that found in able-bodied subjects (172.1±12.6 vs. 168.9±20.6 1/min). This may be explained by the fact that as opposed to the individuals with paraplegia who used a wheelchair daily, able-bodied participants were not trained in arm exercise (Schmid et al., 1998).

We registered a highly significant correlation between the HR, VO_2 and the O_2 pulse (VO_{2max}/HR_{max}[ml/1]) (Astrand and Rodahl, 1986; Schmid et al., 1998). The O_2 pulse expresses the volume of O_2 ejected from the ventricles with each cardiac contraction (Hodgson, 2014). In the present study, the O_2 pulse of the HCycl group was significantly higher than that of the PLift group and the CG and so was VO_2, but not the HR_{max}. This finding suggests an adequate ability of HCycl to maintain or increase venous return and in turn, to increase their cardiac stroke volume due to intact sympathetic vascular innervation (Schmid et al., 1998). Nevertheless, the present study focused only on an analysis of mean values achieved by HCycl athletes with different levels of SCI and inter-group differences would be expected. Indeed, Schmid et al. (1998) demonstrated that individuals with high lesion paraplegia (level of injury between T1 and T4) displayed a lower O_2 pulse during maximal exercise as compared to those with low lesion paraplegia. Conversely, Bernard et al. (2000) demonstrated that physiological responses in well-trained athletes with paraplegia were not necessarily dependent upon the lesion level and there were minimal differences between VO_2, HR and the VE rate between athletes with high- and low-level paraplegia.

HCycl athletes achieved significantly higher P_{max} and LAT at a significantly greater power output as compared to the PLift group and the CG. Greater intensity, energy expenditure and consequently, increased demand for O_2 and removal of CO_2 during the ExT were confirmed by MET and VE which were significantly higher to those observed in the PLift group and the CG. Moreover, LA concentration of HCycl athletes increased significantly compared to the PLift group. Elevated levels of LA concentration could indicate that the individual had exceeded the work rate at which LA could be removed from the blood efficiently or it could be indicative of ischemia or hypoxemia (Gladden, 2004). Stangier et al. (2019) demonstrated higher LA concentrations in handcyclists with SCI at Th12-L1 as compared to LA_{max} in the present study (11.5±2.8 vs. 9.9±3.7mmol/L), indicating greater aerobic capacity of those athletes resulting most likely from a higher level of training (elite athletes including Paralympic medal winners). All of the present results indicate good adaptation and tolerance of high intensity exercise in HCycl athletes.

It should be added that even though the exercise training modalities of the HCycl and PLift groups differed (aerobic vs. anaerobic, respectively), they were all upper-body trained athletes. Moreover, several reviews have concluded that resistance training can also lead to improvements in aerobic fitness (Ozaki et al., 2013; Steel et al., 2012), especially if the intensity of exercise is sufficiently high (Steel et al., 2012). On the other hand, resistance exercise had been part of the training programme of the HCycl group to improve their anaerobic capacity and also strength during performance as well as daily life (Bye et al., 2017). Indeed, P_{max}, LA_{max} and LAT were significantly higher in this group compared to the PLift group.

This study presents some limitations which should be considered. The studied group of handcyclists was heterogeneous in terms of the level of spinal cord lesion. Furthermore, the number of participants was relatively small, and HCycl athletes were older than able-bodied individuals.

Conclusions

In the present study, spinal cord injured handcyclists were found to have excellent aerobic capacity, which is an indirect measure of cardiovascular disease risk. Their cardiorespiratory and metabolic response to the graded exercise test was better than in powerlifters and the physically active non-athlete control group and indicated good exercise tolerance. Their lower HR_{max} seemed to be compensated by potentially higher cardiac stroke volume. These findings emphasize the importance of regular physical exercise and its potential therapeutic role in the prevention of cardiovascular disease in patients with SCI.

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